HAZARD RANGES FOR SMALL NET EXPLOSIVE QUANTITIES IN HARDENED AIRCRAFT SHELTERS

by

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ABSTRACT

An analysis of all available data has been performed to determine the effects of a detonation of small explosive weights inside the U.S. Third Generation Hardened Aircraft Shelters. An explosive weight for a "Zero Quantity-Distance" event has been established. In addition, the quantity-distances (Q-D) for both blast and fragmentation/debris have been established for charge weights up to 500 kg. These quantity-distance ranges are also formulated as proposed changes for both NATO and U.S. Q-D Standards.

BACKGROUND

The DOD Explosives Safety Standard[1] currently contains guidance on the hazard distances which should be associated with U.S. Third Generation Hardened Aircraft Shelters (TGHAS). Quoting from Chapter 10, Section C.2.g.(2), "When the PES is a U.S. third - generation HAS containing up to 5000 Kg NEQ, $20Q^{1/3}$ distances from the front, $25Q^{1/3}$ distances from the sides and $16Q^{1/3}$ distances from the rear shall be used to protect an unhardened ES against debris and blast. With an NEQ of 50 kg or less in a HAS, minimum fragment distances of 80 m to the front and nil to the side and rear are acceptable." While these distances are appropriate for larger Net Explosive Quantities (NEQ's), they are overly conservative for small explosive quantities.

This paper proposes conservatively-realistic quantity-distance (Q-D) relationships for small NEQ's inside U.S. TGHAS. These Q-D relationships are based on a re-analysis of all available full-scale test results involving U.S. TGHAS.

For the purposes of this effort, small Net Explosive Quantities are defined as charge weights up to 500 kilograms. With this limit, let us define four levels of response. It should be noted that the philosophy for establishing these four response levels was proposed by the Danish representative to AC/258 (Group of Experts on the Safety Aspects of Storage and Transportation of Military Ammunition and Explosives) Storage Sub-Group. These are shown below with accompanying anecdotal descriptions.

Very Small NEQ/Zero Q-D (0≤2 Kg). The NEQ is so small in relation to the structure volume that the effects of a detonation (airblast and debris) do not extend outside the structure--a true zero Q.D.

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Small NEQ (2≤50 Kg). In this case, the doors may be damaged and will be expelled. The structure may be slightly damaged but debris range will be no grater than the door range. Airblast will extend beyond the structure.

Medium NEQ (50≤225 Kg). Incipient failure of structure. Airblast and debris extend beyond the structure.

Large NEQ (225≤500 Kg). The structure experiences localized failure. Significant airblast and debris off front and side.

SHELTER DESCRIPTION

The shelter has a double radius arch with an interior clear span of 21.6 meters and a clear height at the crown of 8.4 meters. The overall length of the arch portion is 37.2 meters. It must be noted that this length does not include either the exhaust port at the rear or the front doors with their supporting frames at the front. The interior volume of the shelter is approximately 5,200 m^3.

Ward[2] has estimated that the front door has an areal density of 742 kg/m^2 (152 lbs/f^2). The area of the door is approximately 145 m^2 (1,560 ft^2). Combining these two numbers gives the door a weight of about 107,500 kg (237,000 pounds). In the latest designs, the base of the door is recessed into a track approximately 15 cm (6") deep. It is not clear if earlier versions of the design incorporated this track.

ZERO Q-D

For our purposes, to be a true Zero Q-D” event, two criteria must be satisfied: (1) airblast outside of the structure must be less than that allowed at the inhabited building distance (IBD) and (2) no fragments, debris, or pieces of the structure (including the doors, themselves) shall be projected beyond the structure boundary. The pressure level at the U.S. IBD is 8.3 kPa (1.2 psi); the corresponding pressure level at the NATO IBD is 5.0 kPa 0.725 psi).

Based on several different methods of estimating the airblast produced by a detonation inside a TGHAS, a detonation of about 3.0 kilograms inside such a structure should produce a pressure level at the exterior less than the 5.0 kPa allowed at NATO inhabited building distance.

Two methods have been used to estimate the pressure-loading on the face of the door that is required to initiate movement of the door. The first method assumes the track is not present; the second assumes that it is present.

If the track is not present, the pressure applied to the door must overcome the frictional force between the door and the concrete apron. Thus, for the doors not to move, they should not be exposed to a load greater than their weight multiplied by the appropriate coefficient of friction. The coefficient of friction is approximately 0.5 (note: this is the mid-range for iron on stone). Therefore, for the door not to move, it should not be exposed to a pressure greater than 3.4 kPa (0.5 psi). This loading is produced by the quasi-static gas phase pressure. For these small charge sizes, the shockwave duration is short, so that the reflected pressure and Impulse would not be sufficient to move the door. Estimates of the quasi-static pressure were made using the computer code INBLAST[3]. These estimates are shown in Figure 1 as a function of the NEQ. A detonation of 2.3 kg produces the required quasi-static pressure (3.4 kPa) Inside the structure.

If the track Is present, then the pressure required to initiate movement of the door can be estimated from the torques which would be required to lust begin to lift the door out of Its track. When the overturning and restoring torques are set equal, a pressure of 11.7 kPa (1.7 psi) is obtained. Again, using Figure 1, this would correspond to a charge weight of 8.4 kg.

In order to satisfy both the airblast and debris criteria as well as to be safety conservative, a Net Explosives Quantity (NEQ) of 2 kg (4.4 lbs) has been chosen to define a true “Zero Q-D” event.

TGHAS DATA BASE

For this effort, it was felt that only data obtained from full-scale experiments and computations should be applied. This is because the effects of gravity are not scaled properly In model tests. This becomes extremely important when the structure is not overwhelmed by an internal detonation.

The data collected on four full-scale events form the backbone of the data base. These events are DISTANT RUNNER Events 1, 4, and 5 and the Aircraft Shelter Upgrade Program (ASUP) MK 84 event. The NEQ's for the three DISTANT RUNNER events were 19.1,1,054, and 4,192 kg, respectively. The NEQ for the MK 84 event was 430 kg.

The data base which was prepared for this effort is summarized in Table 1. This table gives both the actual hazard range in meters as well as the corresponding scaled distance in $m/kg^{1/3}$. It is based on compiled information from various sources[1,4-8]. It should be noted that information is presented for two airblast ranges--the U. S. Inhabited Building Distance (IBD) and the NATO (IBD) range. The following sections of the paper describe how most of the entries in this table were generated.

Airblast. Airblast data have been collected for four of the events listed above. The 1 ,054 and 4,192 kg events completely overwhelmed the structure. The 430 kg event was just beyond incipient failure and the 19.1 kg event simply moved the doors.

The external airblast which was recorded on these events is summarized in Figures 2, 3, and 4 for the three primary directions of Front, Side, and Rear. From these airblast plots, airblast hazard ranges can be determined for both the U.S. and NATO IBD criteria as is shown In the Figures. These ranges are shown in Table 2.

Let the airblast hazard range be expressed in the following form:

$$\text{Airblast Hazard Range} = A^{*}Q^{1/3}.$$

The values of A are plotted as functions of NEQ in Figures 5, 6, and 7. The curves shown on these Figures are for purposes of interpolation and do not represent least squares curve fits.

<u>DEBRIS</u>. Debris data have been collected all four of the events discussed in the Airblast section above. It should be pointed out, however, that on the 19.1 kg event, there was no structural damage; the doors were simply pushed away from the shelter. In this case the hazardous debris range was taken as the distance that the doors moved. For all of the other cases, the debris hazard range is defined as the range at which the Pseudo-Trajectory Normal (PTN)[9] debris density reaches a value of 1 hazardous fragment per 55.7 m^2 (600 ft^2), where a hazardous fragment is defined as one having an impact energy of 79 Joules (58 foot-pounds).

The debris data from the remaining three events have been re-analyzed using PTN analysis procedures.[8] Since the original procedures for pseudo-trajectory normal analyses were formulated, several suggestions have been received as to how this technique could be modified and improved. Jacobs, in another paper at this seminar, has presented the latest of these refinements.[10] One of the primary examples given in his paper is an analysis of the ASUP MK 84 test in a U.S. TGHAS. The debris hazard range which he gives for this event is 120 meters (394 feet).

As part of ongoing studies directed at improving the safety and survivability of TGHAS, calculations were performed to estimate the charge size which should cause incipient failure of the structure. These calculations were performed by the New Mexico Engineering Research Insutute.s They utilized a three-dimensional hydrocode (GUSH 3D) to determine the loads on the arch portion of the structure. These loads were then used as inputs to a twodimensional structural response code. This code was SAMSON2, a two-dimensional finite element modeling code. These calculations indicated that a charge weight of approximately 225 kg should be contained within the structure and cause no structural failure, while a charge of 430 kg should cause incipient failure.

All of these debris ranges are shown in Table 1. Using these data in a manner similar to what was done with the airblast, let us define a debris hazard function of the following form:

$$\text{Debris Hazard Range} = B^{*}Q^{1/3}.$$

The values of B are plotted as functions of NEQ in Figure 8. As discussed earlier, the curves shown are for interpolation purposes and do not represent least squares curve fits.

RESULTS

Two types of results can be obtained from a study such as this. The first Is based simply upon what the data indicates would be appropriate hazard ranges. The second result takes this first set of hazard ranges and molds them into proposed changes to the explosives safety standards. The first type of result is directly related and traceable to the input data. The second Is a result of compromise between safety considerations, operational needs, and common sense. This paper presents both results.

Table 3 presents the hazard ranges which are directly derivable from the data described above. Table 4 remolds this information into a proposed change to the DOD Explosives Safety Standard (Note: These proposed changes are only preliminary at this time). Accompanying this Table is a series of notes which explain how each of the values was obtained.

Finally, do these proposed changes accomplish the goal which was set forth at the beginning of this paper? Namely, do they provide a more realistic hazard range without sacrificing explosive safety?

The proposed changes do not sacrifice explosives safety. Rather, they reflect the best judgement at this time as to what the data indicate the criteria should be. Table 5 compares these proposed results with the current values in the DOD Explosives Safety Standards. As can be seen, the proposed changes are less restrictive. Thus, the primary goal of this effort has been accomplished.

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TABLE 1. THIRD GENERATION HARDENED AIRCRAFT SHELTER DATA BASE

NEQ (kg)	W/V (kg/m^3)	FRAGMENTS/DEBRIS RANGE (m) FRONT	SIDE	REAR	REFERENCES
2.0	0.00038	0*	0*	0*	This Paper
19.1	0.0037	6.4	0.0	0.0	4
50.0	0.0096	80**	0.0	0.0	1
225.0	0.0433		0*	0*	5
430.0	0.0827	31.9 (4.2)***	120.0 (15.9)	2.3 (0.3)	6,10
1,054.0	0.2018	214 (21.0)	251 (24.7)	194 (19.1)	7,8
4,192.0	0.8028	324 (20.1)	363 (22.5)	279 (17.3)	7,8

NEQ (kg)	W/V (kg/m^3)	U. S. AIRBLAST (8.3 kPa) RANGE (m) FRONT	SIDE	REAR	NATO AIRBLAST (5.0 kPa) RANGE (m) FRONT	SIDE	REAR	REFERENCES
2.0	0.00038	0*	0*	0*	0*	0*	0*	This Paper
19.1	0.0037	17.4 (6.5)	6.2 (2.3)	0.0	26.5 (9.9)	8.6 (3.2)	0.0	4
50.0	0.0096	na	na	na	na	na	na	none
430.0	0.0827	47.8 (6.3)	23.7 (3.1)	42.4 (5.6)	66.9 (8.9)	38.5 (5.1)	58.5 (7.8)	6
1,054.0	0.2018	na	177.0 (17.4)	78.7 (7.7)	na	286 (28.1)	147 (14.4)	4,8
4,192.0	0.8028	200.9 (12.5)	303 (18.8)	243.3 (15.1)	325 (20.2)	489 (30.3)	401 (24.9)	4,8

*estimated

**Specified in DOD 6055.9-STD

***Numbers in ( ) are scaled distances in m/kg^1/3

na = not applicable

NOTE: structure volume is approximately 5,200 m^3

TABLE 1. THIRD GENERATION HARDENED AIRCRAFT SHELTER DATA BASE

TABLE 2. AIRBLAST HAZARD RANGES

NEQ (kg)	AIRBLAST HAZARD RANGES (meters)					
	U. S. IBD CRITERION			NATO IBD CRITERION		
	FRONT	SIDE	REAR	FRONT	SIDE	REAR
19.1	17.4	6.2	0.0	26.5	8.6	0.0
430	47.8	23.7	42.4	66.9	38.5	58.5
1,054		177.0	78.7		285.6	146.8
4,192	200.9	303.3	243.3	324.6	489.1	401.1

TABLE 2. AIRBLAST HAZARD RANGES

TABLE 3. DATA-DERIVED TGHAS HAZARD RANGES

CATEGORY	Q (kg)	FRAGMENT/DEBRIS		
		FRONT	SIDE	REAR
VERY SMALL NEQ	0--2	0	0	0
SMALL NEQ	2--50	80	0	0
MEDIUM NEQ	50--225	6.3Q^.333	0	0
LARGE NEQ	225--500	6.3Q^.333	15Q^0.333	25

CATEGORY	Q (kg)	U. S. AIRBLAST			NATO AIRBLAST		
		FRONT	SIDE	REAR	FRONT	SIDE	REAR
VERY SMALL NEQ	0--2	0	0	0	0	0	0
SMALL NEQ	2--50	6.5Q^.333	2.2Q^.333	0.5Q^.333	9.9Q^.333	3.2Q^.333	0.7Q^.333
MEDIUM NEQ	50--225	6.5Q^.333	2.4Q^.333	3.1Q^.333	9.9Q^.333	3.6Q^.333	4.1Q^.333
LARGE NEQ	225--500	6.5Q^.333	4.0Q^.333	6.0Q^.333	9.9Q^.333	6.6Q^.333	8.6Q^.333

NOTE: ALL RANGES ARE IN METERS

TABLE 3. DATA-DERIVED TGHAS HAZARD RANGES

TABLE 4. PROPOSED NATO/U.S. SMALL NEQ QUANTITY-DISTANCE CRITERIA FOR INHABITED BUILDING DISTANCE*

U.S. THIRD GENERATION HARDENED AIRCRAFT SHELTER

(NOMINAL VOLUME 5,200 m^3)

CATEGORY	NEQ (kg)	FRONT (m)	SIDE (m)	REAR (m)
VERY SMALL NEQ	0<=2	15 (1)	15 (1)	15 (1)
SMALL NEQ	2<=50	70 (2)	15 (3)	15 (4)
MEDIUM NEQ	50<=225	70 (2)	15 (5)	20 (6)
LARGE NEQ	225<=500	70 (2)	120 (7)	50 (8)

Items denoted by ( ) refer to the footnotes shown below.
All quantity-distance ranges shown are based on the shelter doors being closed.

FOOTNOTES FOR US/NATO PROPOSAL

1. Analyses have shown that this should have a zero Q-D.
   A 15m minimum distance for fire hazard is applied.
2. Current value is U.S DoD 6055.9-STD (Reference 1) is 80m.
   The 70 m value is based on improved debris throw and airblast estimates.
3. A 2.2Q^.333 fit to the airblast data (U.S. criterion) gives a range of 8 meters for 50 kg.
   A 3.2Q^.333 fit to the airblast data (NATO criterion) gives a range of 12 meters for 50 kg.
   A 15 meter minimum fire hazard distance is applied.
4. A 0.5Q^.333 fit to the airblast data (U.S. criterion) gives a range of 2 meters for 50 kg.
   A 0.7Q^.333 fit to the airblast data (NATO criterion) gives a range of 3 meters for 50 kg.
   A 15 meter minimum fire hazard distance is applied.
5. A 2.4Q^.333 fit to the airblast data (U.S. criterion) gives a range of 15 meters for 225 kg.
   A 3.6Q^.333 fit to the airblast data (NATO criterion)gives a range of 22 meters for 225 kg.
   A 15 meter minimum fire hazard distance is applied.
6. A 3.1Q^.333 fit to the airblast data (U.S. criterion) gives a range of 19 meters for 225 kg.
   A 4.1Q^.333 fit to the airblast data (NATO criterion) gives a range of 25 meters for 225 kg.
   A value of 20 m has been selected.
7. Reference (9)
8. A 6.0Q^.333 fit to the airblast data (U.S. criterion) gives a range of 48 meters for 500 kg.
   A 8.6Q^.333 fit to the airblast data (NATO criterion) gives a range of 68 meters for 500 kg.
   A value of 50 m has been selected.

*NOTE: These proposed changes are preliminary at this time.

TABLE 4. PROPOSED NATO/U.S. SMALL NEQ QUANTITY-DISTANCE CRITERIA FOR INHABITED BUILDING DISTANCE*

TABLE 5. COMPARISON OF PROPOSED CHANGE TO TGHAS QUANTITY-DISTANCE WITH CURRENT DOD 6055.9-STD VALUES

NEQ	PROPOSED CHANGE			CURRENT DOD 6055.9-STD		
(kg)	FRONT	SIDE	REAR	FRONT	SIDE	REAR
2	15	15	15	80	20	20
5	70	15	15	80	27	27
10	70	15	15	80	34	34
20	70	15	15	80	43	43
40	70	15	15	80	55	55
60	70	15	20	80	98	63
80	70	15	20	86	108	69
100	70	15	20	93	116	74
200	70	15	20	117	146	94
400	70	120	50	147	184	118
500	70	120	50	159	198	127

CURRENT U.S. STANDARDS:

1. NEQ < 50 kg, 80 m to the front based on debris, and 16Q^.333 to the side and rear based on airblast. In current practice, only the debris criterion is applied.
2. For NEQ between 50 and 5000 kg, the following apply:
   20Q^.333 to the front with an 80 m minimum
   25Q^.333 to the side
   16Q^.333 to the rear

TABLE 5. COMPARISON OF PROPOSED CHANGE TO TGHAS QUANTITY-DISTANCE WITH CURRENT DOD 6055.9-STD VALUES

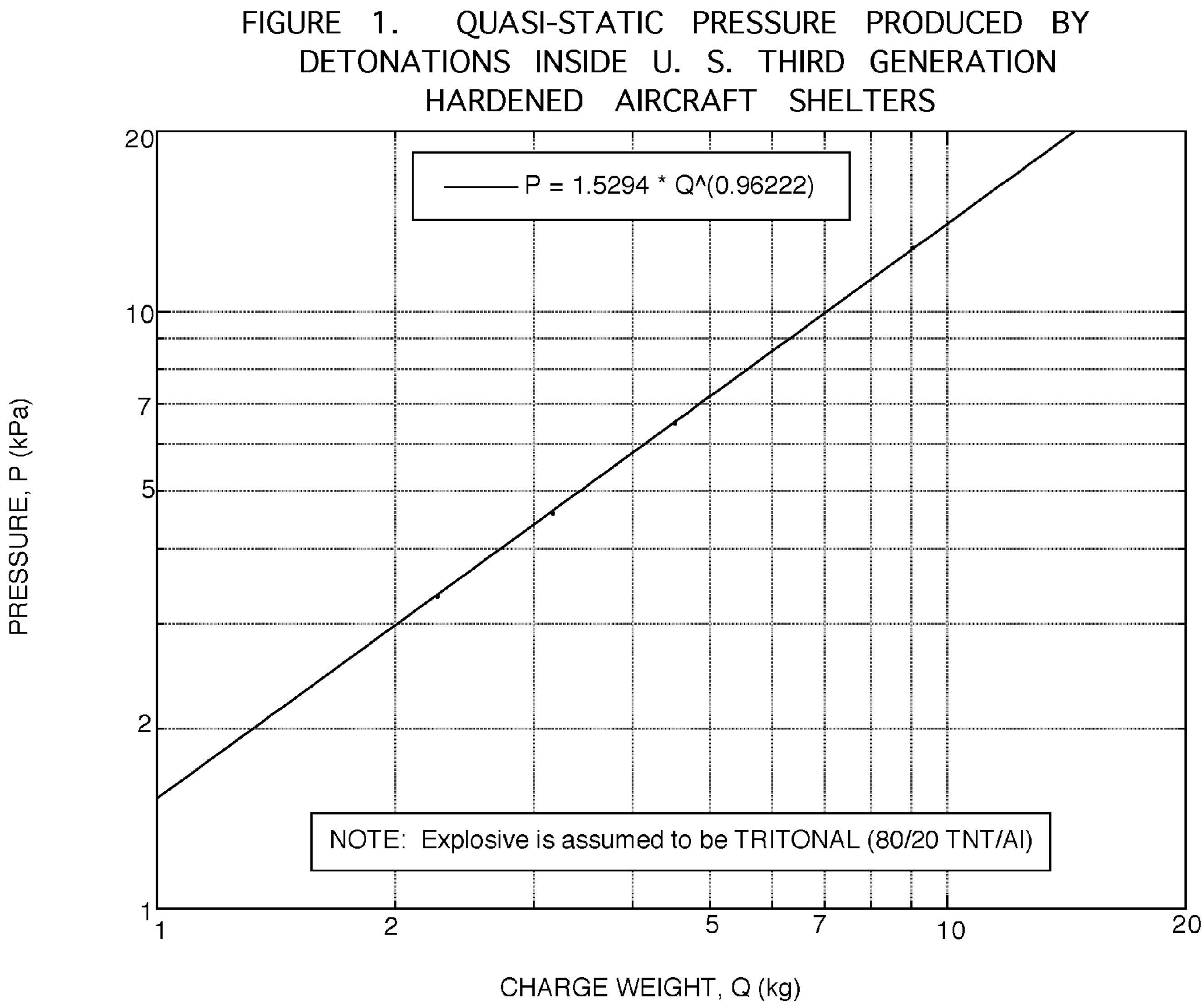

FIGURE 1. QUASI-STATIC PRESSURE PRODUCED BY DETONATIONS INSIDE U. S. THIRD GENERATION HARDENED AIRCRAFT SHELTERS

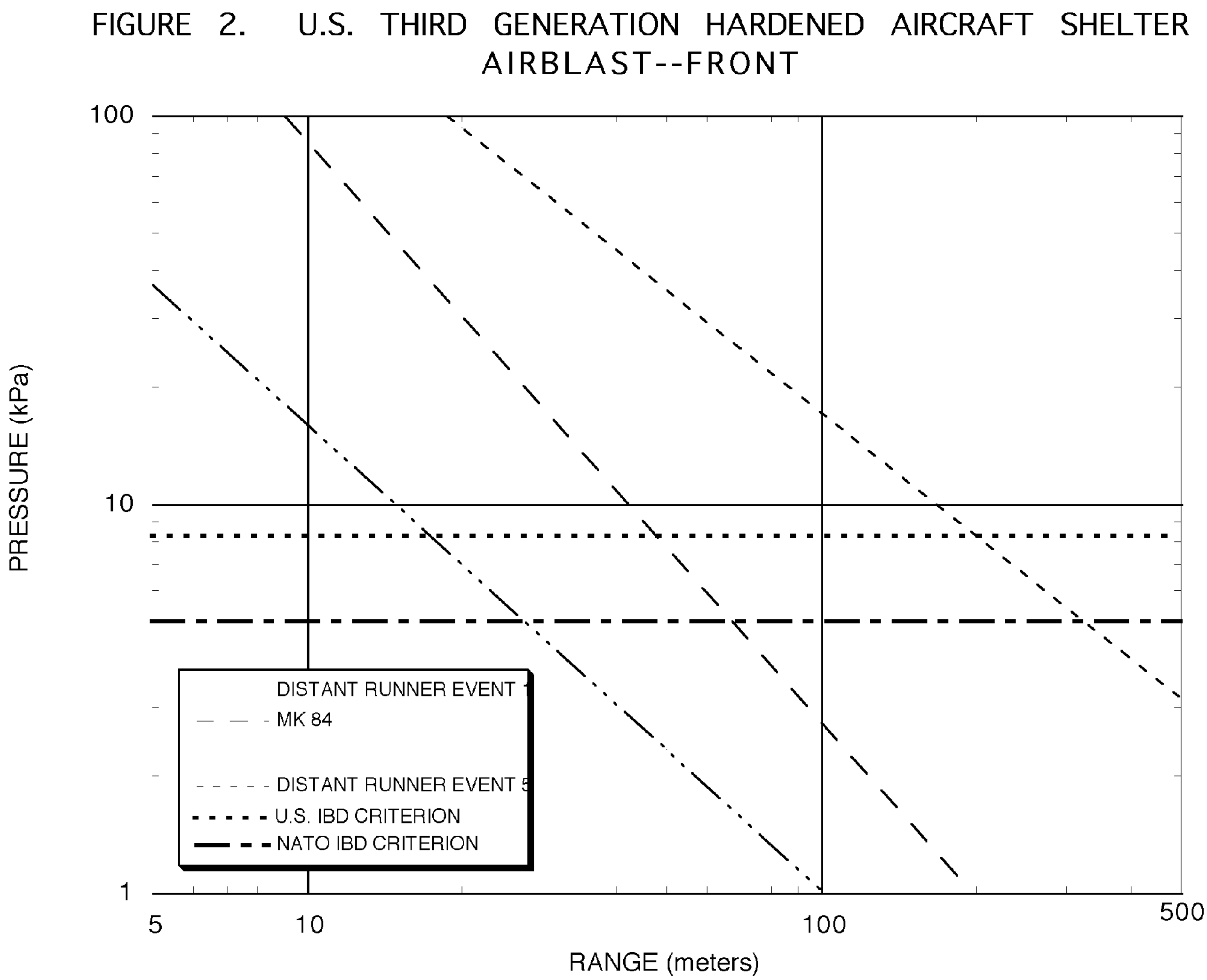

FIGURE 2. U.S. THIRD GENERATION HARDENED AIRCRAFT SHELTER AIRBLAST--FRONT

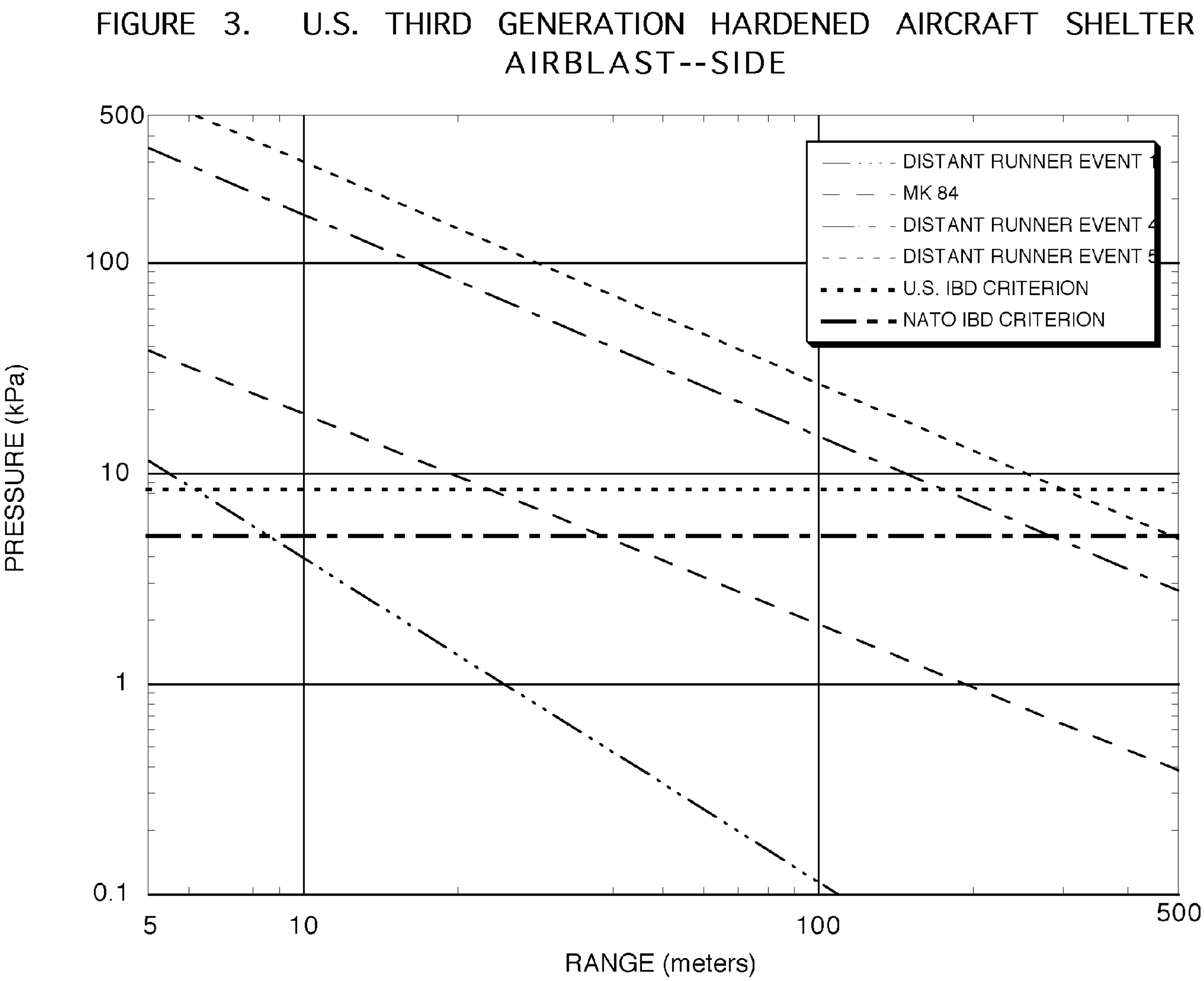

FIGURE 3. U.S. THIRD GENERATION HARDENED AIRCRAFT SHELTER AIRBLAST--SIDE

FIGURE 4. U.S. THIRD GENERATION HARDENED AIRCRAFT SHELTER AIRBLAST--REAR

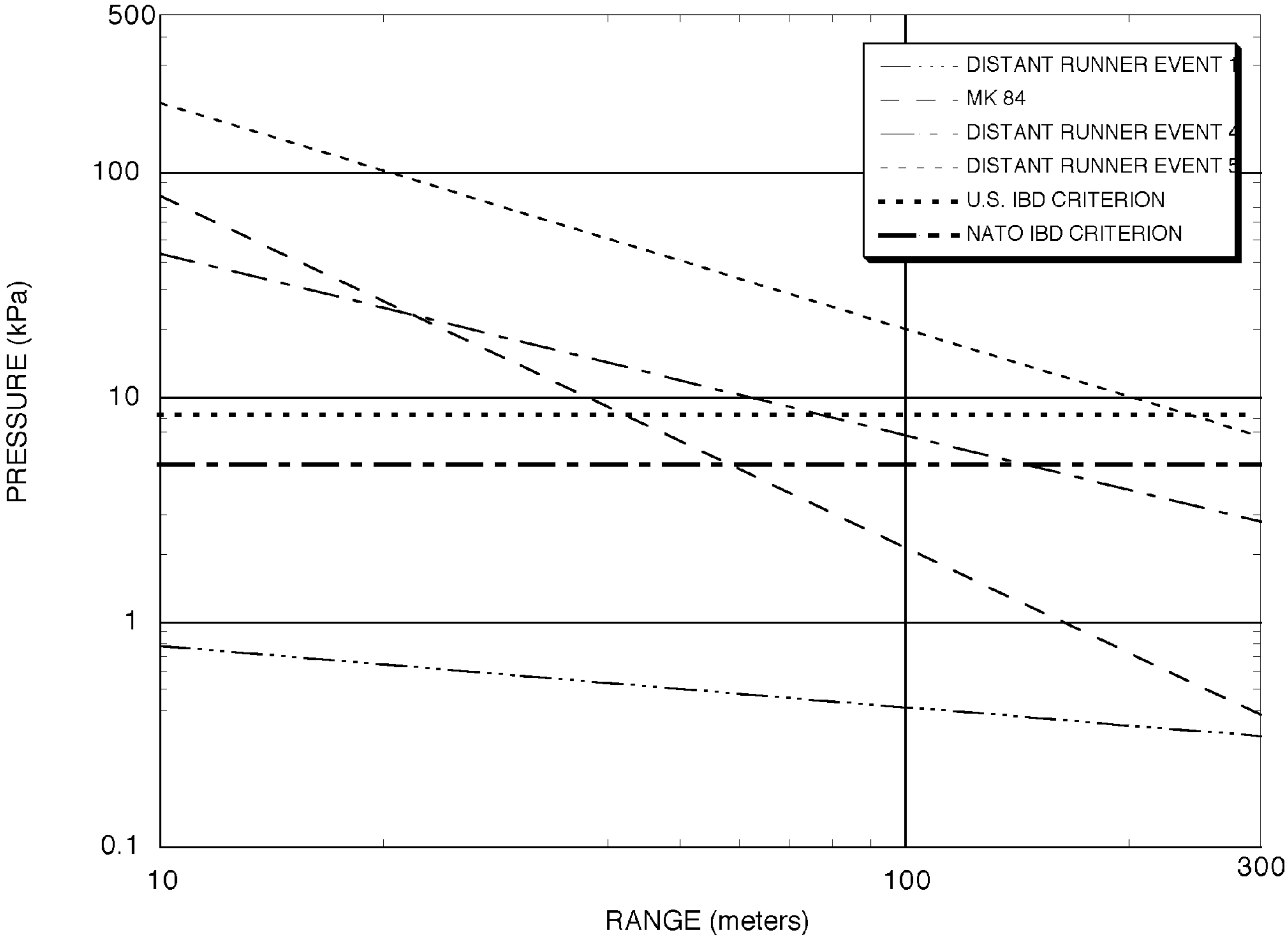

FIGURE 4. U.S. THIRD GENERATION HARDENED AIRCRAFT SHELTER AIRBLAST--REAR

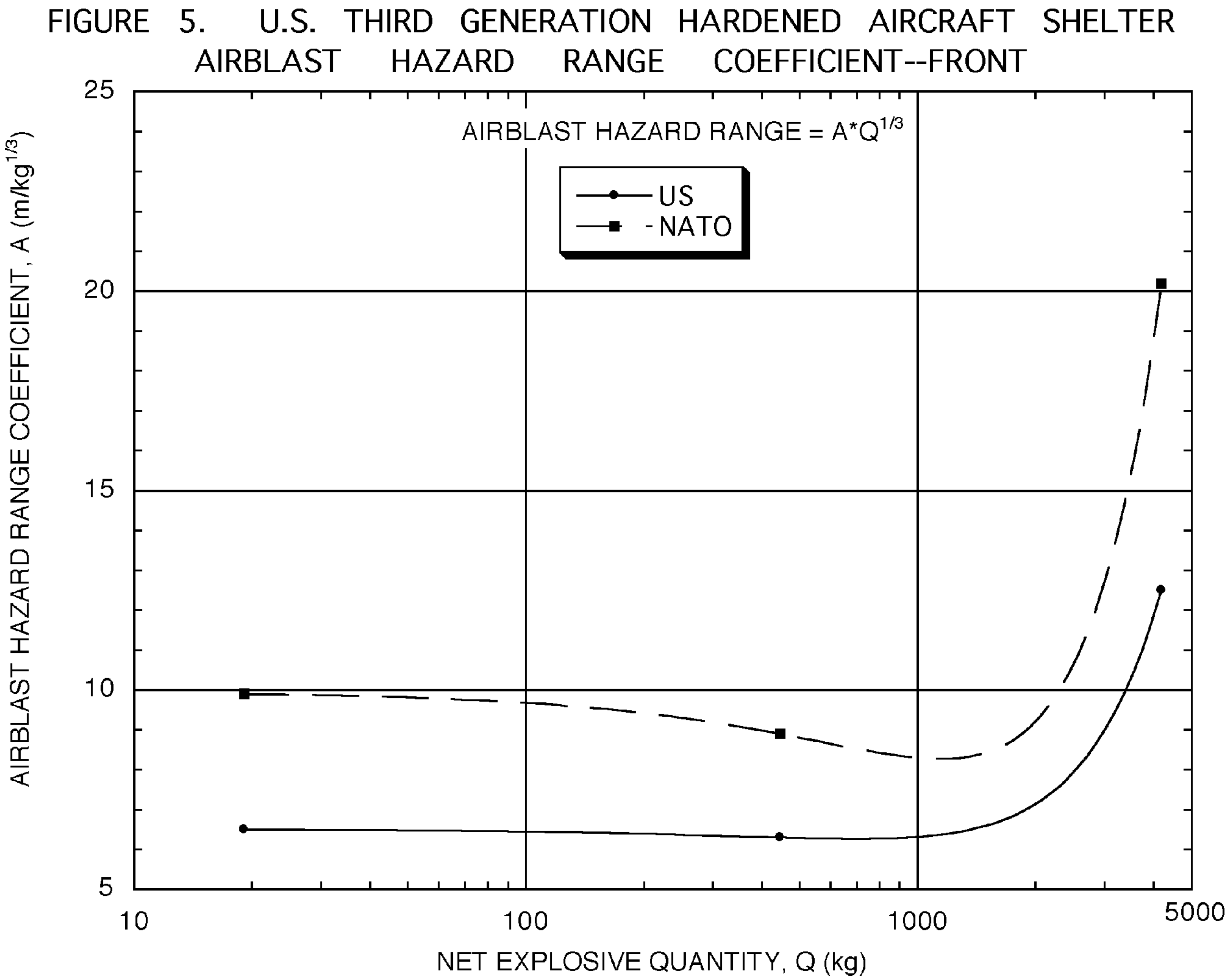

FIGURE 5. U.S. THIRD GENERATION HARDENED AIRCRAFT SHELTER AIR BLAST HAZARD RANGE COEFFICIENT--FRONT

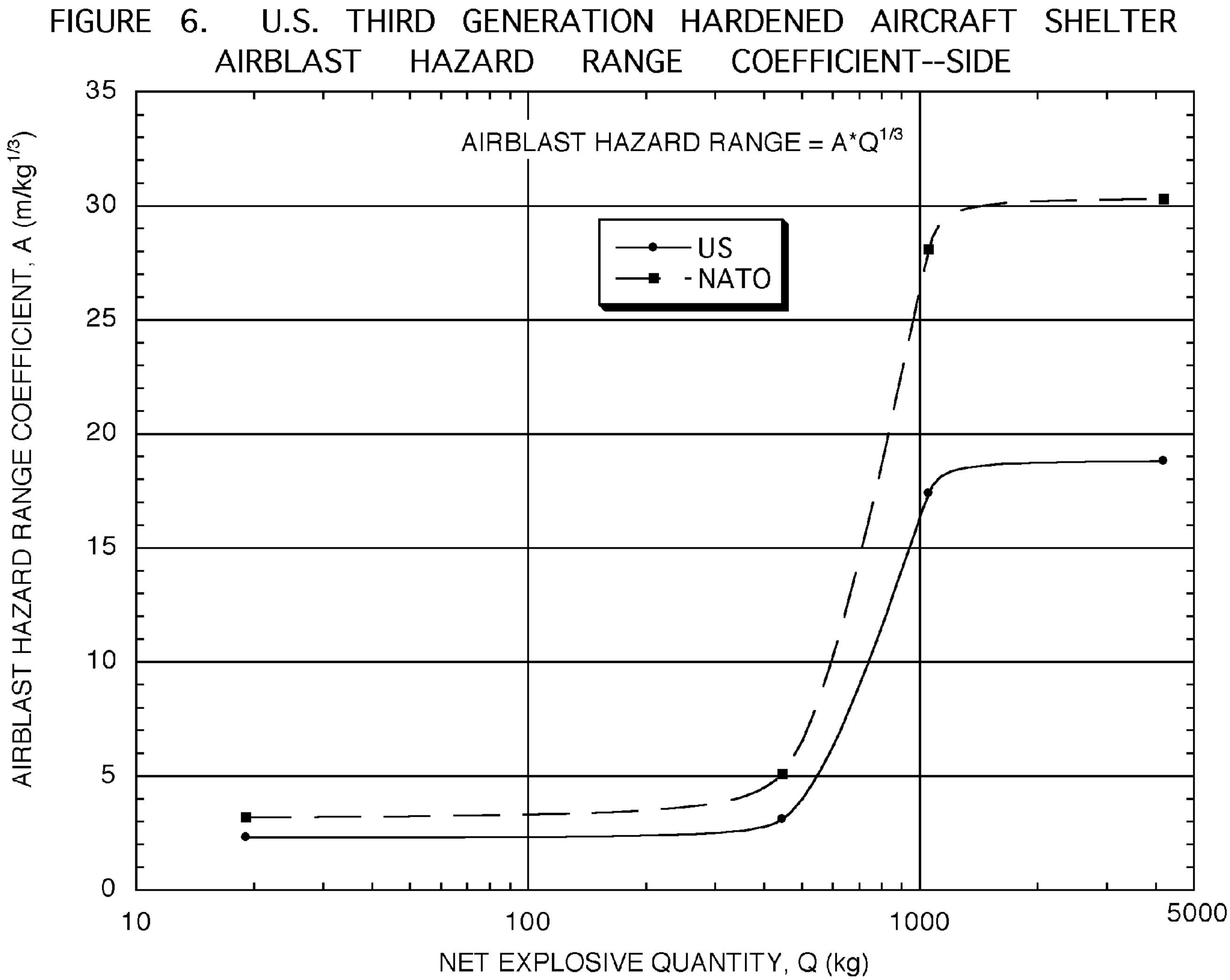

FIGURE 6. U.S. THIRD GENERATION HARDENED AIRCRAFT SHELTER AIRBLAST HAZARD RANGE COEFFICIENT--SIDE

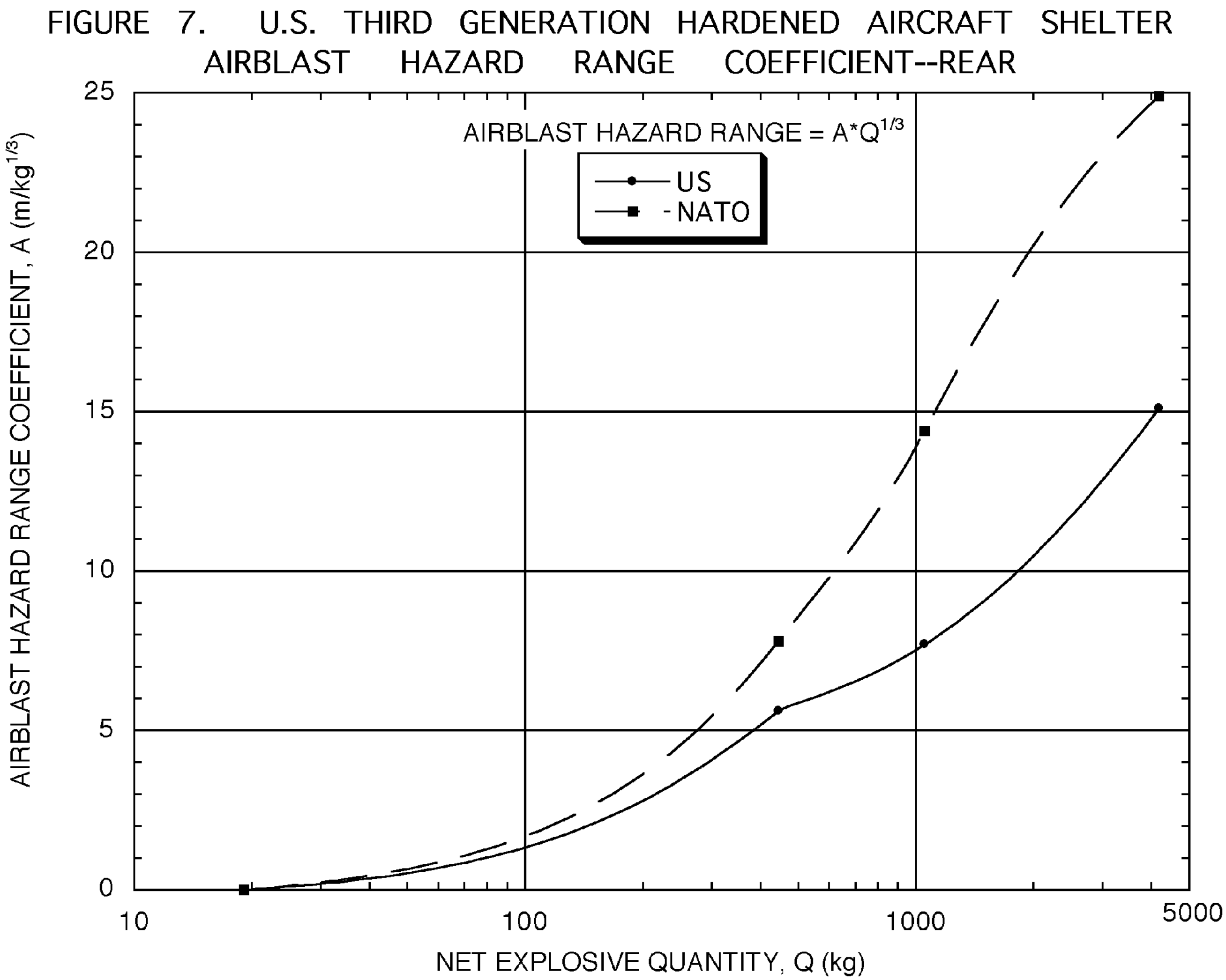

FIGURE 7. U.S. THIRD GENERATION HARDENED AIRCRAFT SHELTER AIRBLAST HAZARD RANGE COEFFICIENT--REAR

FIGURE 8. U. S. THIRD GENERATION HARDENED AIRCRAFT SHELTER DEBRIS HAZARD RANGE COEFFICIENTS

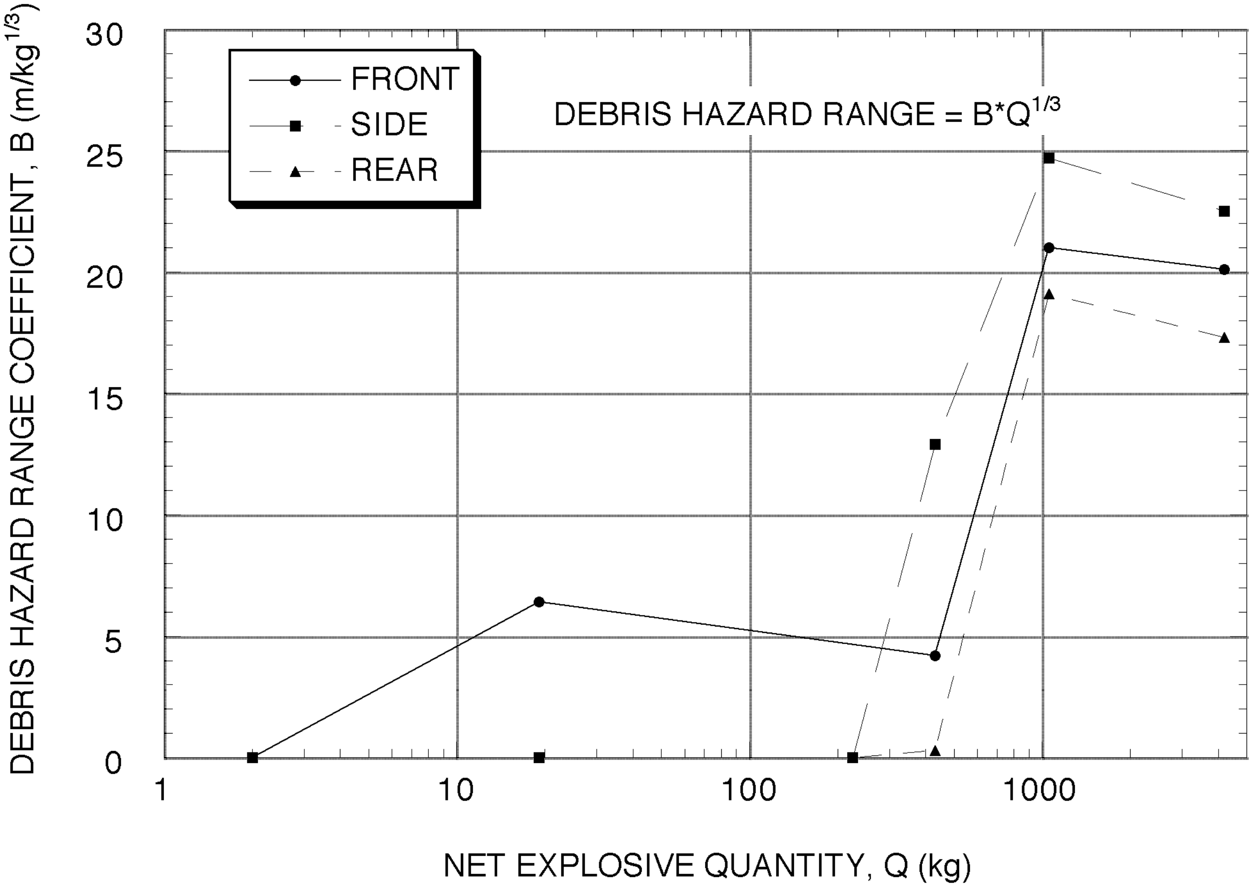

FIGURE 8. U. S. THIRD GENERATION HARDENED AIRCRAFT SHELTER DEBRIS HAZARD RANGE COEFFICIENTS